MEPAG
E2E-iSAG

Planning for what the science community of the future would do with the samples once received,

Lisbon, Portugal; June 16, 2011

Monica Grady, on behalf of the E2E-iSAG committee

Pre-decisional: for discussion purposes only

Overview

Prioritized MSR science objectives

Derived implications

- Samples required/desired to meet objectives
- Measurements on Earth

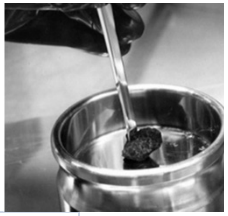
Critical Science Planning Questions for 2018

- Variations of interest?
- # of samples?
- Types of landing sites that best support the objectives?
- Sample size?
- Measurements needed to interpret & document geology and select samples?
- On-Mars strategies?

Engineering implications

- Sampling hardware
- Instruments on sampling rover
- EDL & mobility parameters, lifetime, ops scenario
- Sample preservation

Where This Module is Going

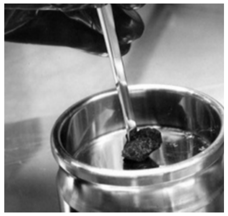


SEDIMENTARY		IGNEOUS			
Mass (g)		**Mass (g)**		**Goal**	**Technical notes**
total	meas.	total	meas.		
Phase I Initial Examination					
0.00		0.00		Get enough info. to make decisions about what to do with sample. How heterogeneous? How to sub-divide? Large scale mineralogy and surface	Preliminary examination using stand-off instruments only; non-destructive
0.00		0.00			Preliminary examination using stand-off instruments only; minimally destructive
Phase II Planetary Protection					
1.50		1.50		Assess life and biohazard	
Phase III. Research					
1.85		1.21		Microanalysis of polished surfaces	Inorganic chemistry, organic chemistry, mineralogy, petrology, isotope geochemistry. Assume a need to prepare 5 thin sections and 1 thick section from each sample.
				Fluid inclusion analysis. Demountable thick sections (100 mm thick)	
0.15	0.05	0.15	0.05	Microanalysis of individual subsamples -- number depends on heterogeneity	Inorganic chemistry, organic chemistry, mineralogy, petrology, isotope geochemistry
3.00	1.00	3.00	1.00	Bulk Analyses	Soluble & insoluble organic analysis
		2.25	0.75		Internal isochron geochronology, multiple isotopic systems.
1.50	0.50	1.50	0.50		Bulk composition; stable isotope geochemistry
0.30	0.10	0.30	0.10		Gas extraction by crushing and heating to get major fluid phases (CO_2, H_2O, perhaps some noble gases)
0.60	0.20			Clastic sediment component analysis	number of grains analyzed (≥100) and number of distinct components (e.g., lithic, phosphate, plagioclase grains). Individual lithic grains of ≥1 mg required for analysis
1.00		1.00		Follow-up for unexpected results	
Phase IV. Sample Mass held for Future Researchers					
6.00		6.00		Future research	Pristine storage for future researchers
15.9		16.9		Subtotal	
5%		5%		*Factor for sample re-use and future improvements in efficiency*	Current figure is a conservative guess. Needs detailed study by a future science planning team
15.1		**16.1**		**Total sample mass**	

Derive mass per sample

Pre-decisional: for discussion purposes only

Measurements required—Rock Samples



MAJOR CATEGORIES IN SEQUENTIAL ORDER

Ref.	Investigation/Topic	
1	**Preliminary Examination before opening**	
2	**Peliminary Examination after opening**	
	b	Non-destructive science involving whole cores
	INITIAL SUBDIVISION OF SAMPLES	
3	a	Extant life detection
	b	Biohazard assessment
4	**Pristine storage for future researchers**	
	ALLOCATIONS OF SUBSAMPLES TO PIs	
5	**Microanalysis of polished surfaces**	
6	**Microanalysis of small subsamples (<10 mg)**	
7	**Bulk Analyses (typically >100 mg)**	
	a	Geochronology
	b	Organic geochemistry
	c	Quantitative sedimentology
	d	Bulk composition, stable isotope analysis
	e	Fluid inclusion, gas extraction

The Draft Test Protocol (Rummel et al., 2002) analyzed these three together.

The proposed scientific objectives of the MSR campaign would require measurements of suites of returned samples in all of these categories.

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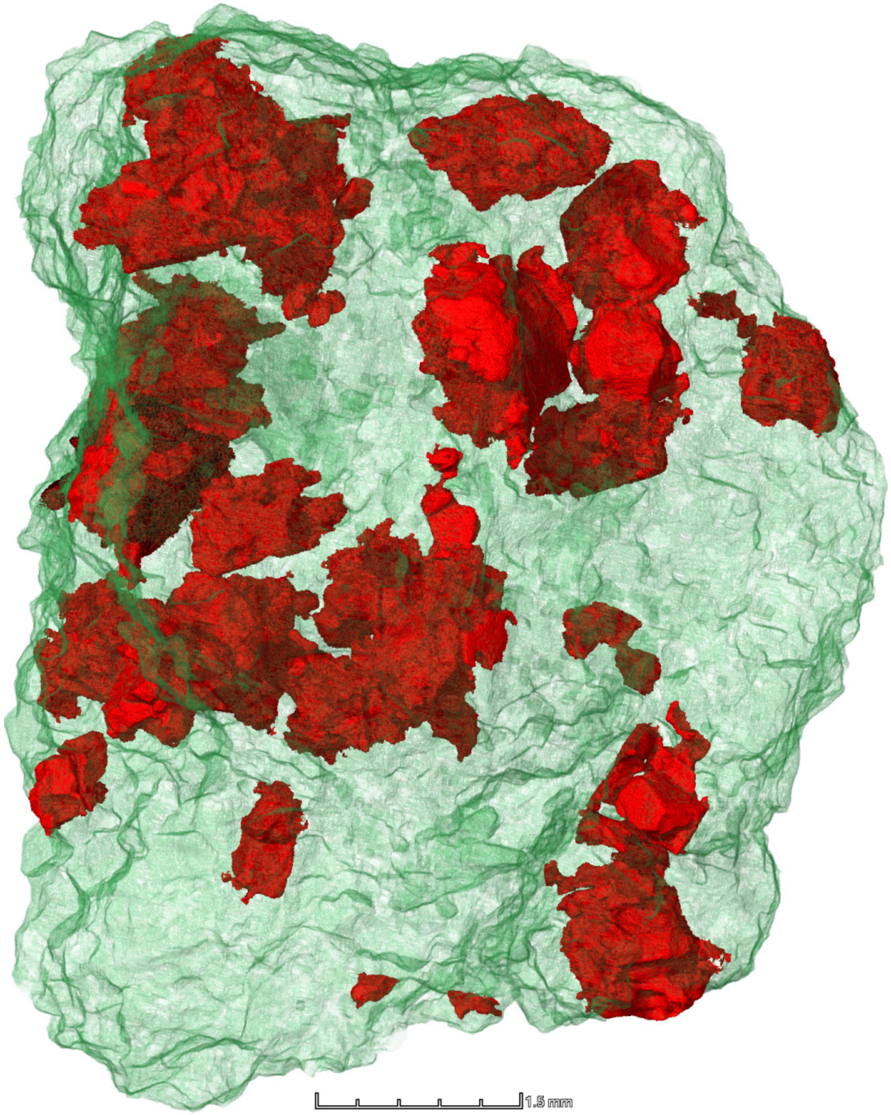
1. CT Scanning

DRAFT FINDING: CT scanning technology has advanced enormously in the last several years, and would be incredibly valuable to MSR for non-destructive sample assessment.



A CT scan of a chip from the Nakhla martian meteorite, showing the 3-D distribution of olivine grains (red) within the meteorite. Spatial resolution is 5 μm. Credit: A.W. Needham (OU) and the EMMA Dept of the NHM.

2b. Non-Destructive Whole Core Science

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Paleomagnetism

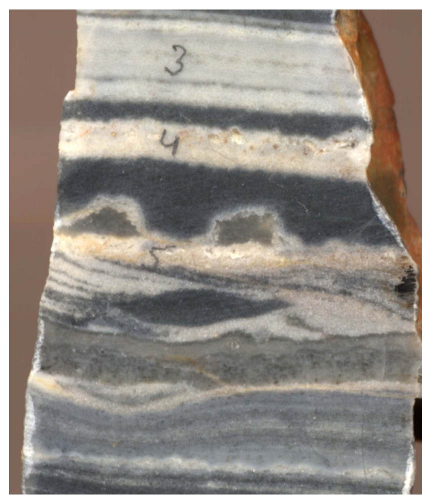
DRAFT FINDING: For a suite of samples with known stratigraphic age, an important measurement would be intensity and orientation of the remanent magnetism. Such data would constrain the duration and magnitude of the Martian geomagnetic dynamo by establishing when the field was absent or present.

Visible Texture and Structure

Example – chemotrophy in mudflat sediments, Pilbara, 3.5 Ga

From Frances Westall, 2011

DRAFT FINDING: Meso-scale texture and structure should be investigated before the sample is split.



Volcanic sand, pore spaces

Stable sediment surface (exposed to sunlight)

Hydrothermal vein

3. Life Detection and Biohazard Assessment

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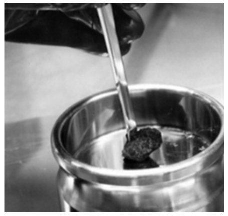
Key Relevant Assumptions:

1. The Mars surface operations team would want to collect samples that are very diverse.

   Because of this diversity, it would presumably not be possible to extrapolate Life Detection/Biohazard (LD/BH) test results from one sample to another, and that a split from every sample would need to go through LD/BH testing.
2. If extant martian life is present in the returned samples, it may be spatially heterogeneous. However, we wouldn't have a credible way of estimating its distribution, or understanding the factors that control it, until the samples are studied on Earth.
3. Decisions about how to split samples, and how to use the splits (in response to diversity and heterogeneity), would need to be reviewed and modified as LD-BH testing proceeds (e.g. see Draft Protocol).
   - Once the spatial heterogeneity of martian biology (should it be detected) in rock and soil samples is known it would constitute a primary driver for sample subdivision strategies.

With assistance from Margaret Race

3. Life Detection and Biohazard Assessment (cont.)



There are two primary logical outcomes:

- CASE A. 100% of the LD-BH tests are negative.
- CASE B. At least one of the LD-BH tests is positive.

For CASE A:

- Most detailed published estimate of sample mass needed (for LD-BH-prel. exam): **10% of an assumed returned sample** mass of 500-1000 g (Rummel et al., 2002).
  - The 10% figure not a rule—intent was to be a reasonable starting place to guide discussions.
  - Similar results previously obtained by DeVincenzi and Bagby (1981)—assumed 100 g needed out of 1000 g returned.

For CASE B:

- For reasons related both to science and to PP, the priorities for how the sample mass would be used would change dramatically, given this result. This could be the most important scientific discovery of our lifetime!

With assistance from Margaret Race

Establishing a Sample Reserve for the Future

The concept of a Sample Reserve is in line with recent and long-established curatorial practices for extraterrestrial materials:

- The Hayabusa team has specified that 45 % of their asteroid sample be held in reserve.
- Allocation of Apollo lunar rocks and soils is restricted to 50% of any specific sample. Allocation of additional material is possible only following very detailed (and skeptical) CAPTEM review.
- Current policy in Stardust is to hold 50% of the cometary sample in reserve
- For all meteorites the long-standing rule used by the British Natural History Museum is no more than 1% of total holdings per request and no more than 10% in 'curator's lifetime'.

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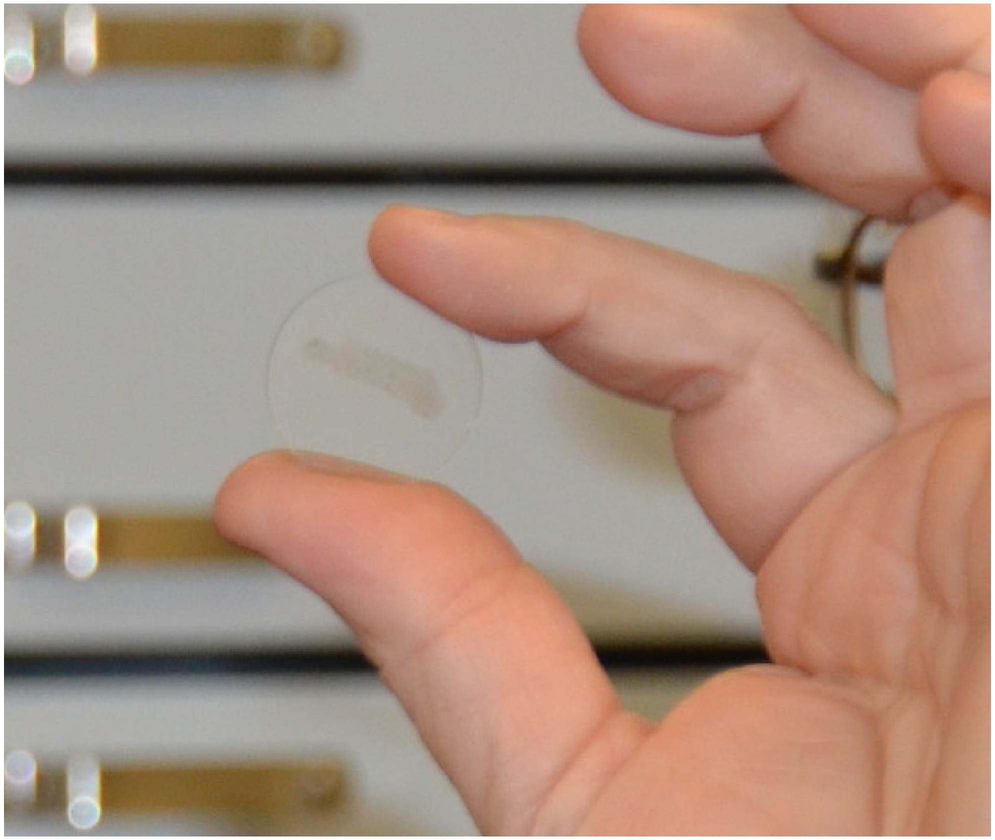
	e	Fluid inclusion, gas extraction

The gift that keeps on giving…

<u>DRAFT FINDING:</u> Not less than 40% by mass of each sample should be set aside as a reserve to support future science.

With input from Tim McCoy (Smithsonian Institute) and Caroline Smith (Natural History Museum).

5. Microanalysis of polished surfaces



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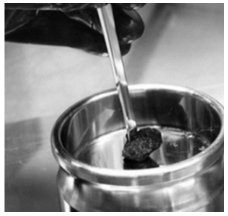
Sample is one of the Mars meteorite thin sections in the collection at the Smithsonian Institution.

- This is one of the most useful preparations for sample science—it enables a wide range of microbeam methods.
- Estimated mass needed (6 sections): **Igneous: 1.2 g; Sedimentary: 1.9 g**

5. Polished Surface Science



Polished thin section is one of most useful preparations for sample science—it enables a wide range of microbeam methods.

Name	What	Information
Type 1. Non-destructive		
Optical microscopy		mineral composition, texture
ESEM	Environmental Scanning Electron Microscopy	ultrastructure, morphology
EDX	energy dispersive X-ray spectroscopy (EPMA -ELECTRON MICROPROBE ANALYSIS)	elemental composition and distribution
Micro-Raman	Micro-Raman spectroscopy	mineral composition
micro-XRF	micro X-ray fluorescence	elemental composition
SAM	Scanning Auger Microscopy	elemental composition and distribution
HR FEG-SEM	field emission gun-based High Resolution Scanning Electron Microscopy	ultrastructure, morphology
AFM	Atomic Force Microscopy	3-D topography down to the angstrom level
EBSD	Electron Backscatter Diffraction	ultrastructure
micro-XRD	micro-X-ray diffraction	mineral composition
AES	Auger Electron Spectroscopy	elemental composition and distribution
Type 2. Almost non-destructive		
SIMS	Secondary Ion Mass Spectrometry	elemental and isotopic composition
ToF-SIMS	Time-of-Flight Secondary Ion Mass Spectrometry	3-D imaging, elemental composition and distribution
LA-ICP-MS	Laser Ablation Inductively Coupled Plasma Mass Spectrometry	elemental composition and distribution
micro-FTIR	Fourier Transform Infrared Spectroscopy	chemical composition and distribution
Type 3. Destructive		
TEM	Transmission electron microscopy	ultrastructure, morphology

6. Microanalysis of small samples

Name	What	Sample mass (typical)	Science information generated
AMS	Accelerator Mass Spectrometry		
CL	cathodoluminescence		
confocal RAMAN microscopy			
EBSD	Electron backscatter diffraction		
EDX	energy dispersive X-ray spectroscopy (EPMA - ELECTRON MICROPROBE ANALYSIS)		
ESR spectroscopy	electron spin resonance		
FTIR / micro FTIR	FOURIER TRANSFORM INFRARED SPECTROSCOPY		
HPLC	High-performance liquid chromatography		
ICP-MS			
in situ RAMAN microanalysis			
INAA	Instrumental Neutron Activation Analysis		concentration of trace and major elements
LA-ICP-MS	Laser Ablation Inductively Coupled Plasma Mass Spectrometry		
microXRF	micro X-ray fluorescence		
microXRF	micro X-ray fluorescence		
PIXIE / PIXE / PIGE	Proton-induced X-ray and gamma-ray emission (PIXE / PIGE)		
RAMAN			
SAM	Scanning Auger Microscopy (AES - Auger Electron Spectroscopy)		
SIMS / nanoSIMS	Secondary Ion Mass Spectrometry		
STXM	scanning-transmission X-ray microscopy		
STXM	scanning-transmission X-ray microscopy		
TEM	Transmission electron microscopy		
ToF-SIMS	Time-of-flight Secondary Ion Mass Spectrometry		
XANES	X-ray near-edge structure spectroscopy		
TOTAL MASS			

NEED TO DEVELOP

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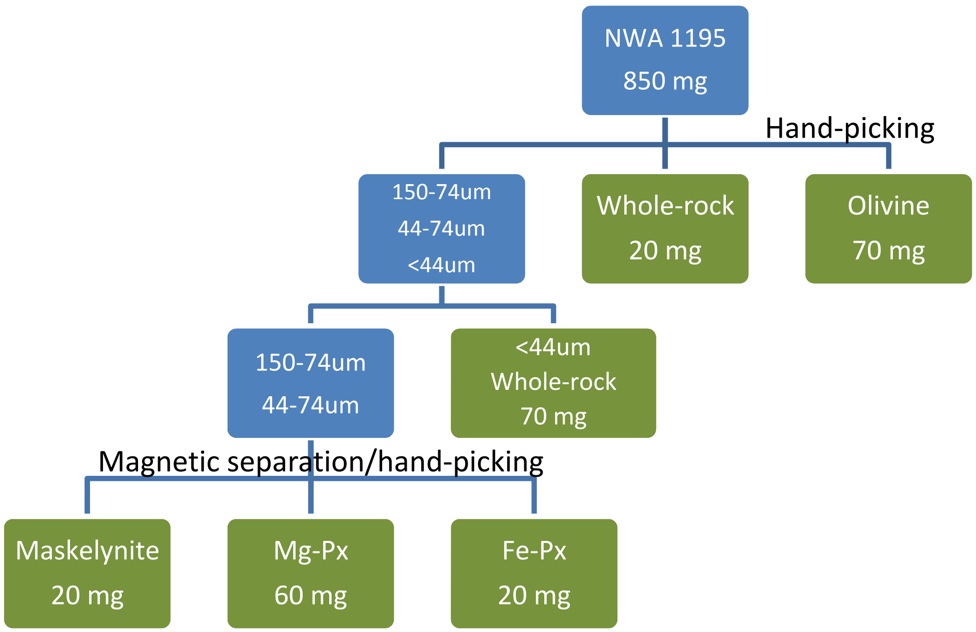
- A large number of different types of investigation could be carried out on small (<5 um) sample fragments.
- **Estimated mass needed 150 mg.**

7a. Geochronology

Example: NWA 1195



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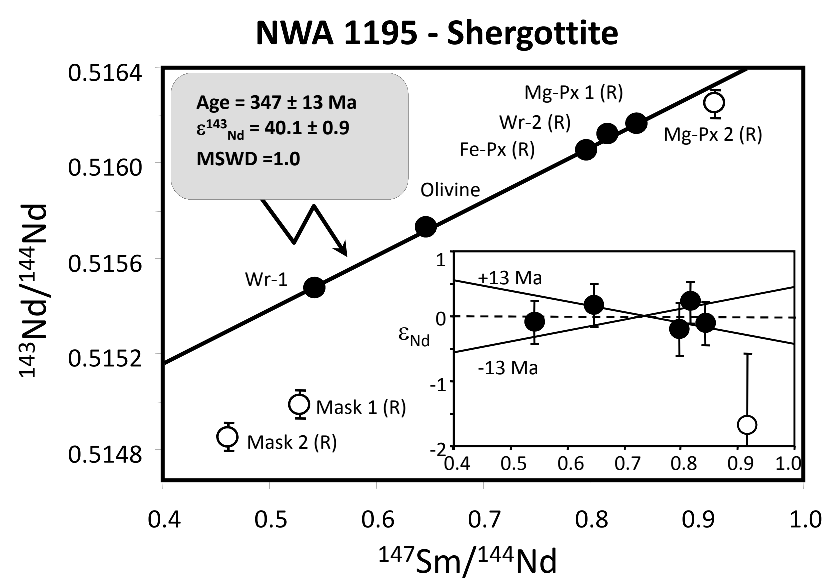
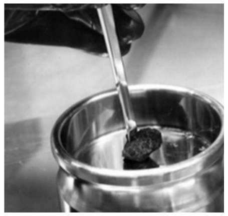


Required starting mass depends on:

- Grain-size distribution
  - Need more for coarse-grained
  - Need less for fine-grained
- Concentration of trace element of interest
- Isotopic system to be studied

7a. Geochronology (cont).



Class	Sample	Mass Studied (g)	Isotopic system studied	Reference
Shergottite	Zagami	2.0	Rb-Sr, Sm-Nd, and U-Pb	Borg et al. (2005)
	ALH 84001	1.6	Lu-Hf and Sm-Nd chronology	Lapen et al. (2010)
	ALH 84001	1.0	High-precision 142Nd/144Nd	Lapen et al. (2010)
	DaG 476	0.984	Lu-Hf and Sm-Nd whole-rock isotopic systematics	Debaille et al. (2008)
	NWA 1195	0.85	Rb-Sr and Sm-Nd chronology	Symes et al. (2008)
	SaU 008	0.692	Lu-Hf and Sm-Nd whole-rock isotopic systematics	Debaille et al. (2008)
	DaG 476	0.64	Rb-Sr and Sm-Nd chronology	Borg et al. (2003)
	ALH 77005	0.537	Rb-Sr and Sm-Nd chronology	Borg et al. (2002)
	NWA 856	0.34	Rb-Sr and Sm-Nd chronology	Brandon et al. (2004)
	QUE 94201	0.33	Rb-Sr and Sm-Nd chronology	Borg et al. (1997)
	EET 79001A	0.32	Lu-Hf and Sm-Nd whole-rock isotopic systematics	Debaille et al. (2008)
	Los Angeles	0.278	Lu-Hf and Sm-Nd whole-rock isotopic systematics	Debaille et al. (2008)
	Shergotty	0.235	Lu-Hf and Sm-Nd whole-rock isotopic systematics	Debaille et al. (2008)
	LEW 88516	0.222	Rb-Sr and Sm-Nd chronology	Borg et al. (2002)
Dunite	Chassigny	1.7	Rb-Sr, Sm-Nd, and Ar-Ar chronology	Misawa et al. (2006)
	NWA 2737	0.043	Ar-Ar thermal history	Bogard and Garrison (2008)
Nakhlite	Governador Valadares	0.58	Rb-Sr and Sm-Nd chronology	Shih et al. (1999)
	Lafayette	0.5	Rb-Sr and Sm-Nd chronology	Shih et al. (1998)
	Lafayette	0.097	Ar-Ar thermal history	Podosek (1973)
	Nakhla	0.071	Ar-Ar thermal history	Podosek (1973)
Average		**0.753**	(average includes full chronology studies only)	

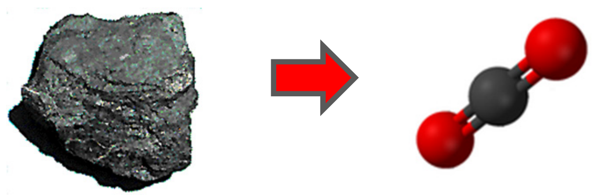
Planning figure used

7b. Organic Geochemistry

2) Measure carbon content

Does the rock contain carbon?

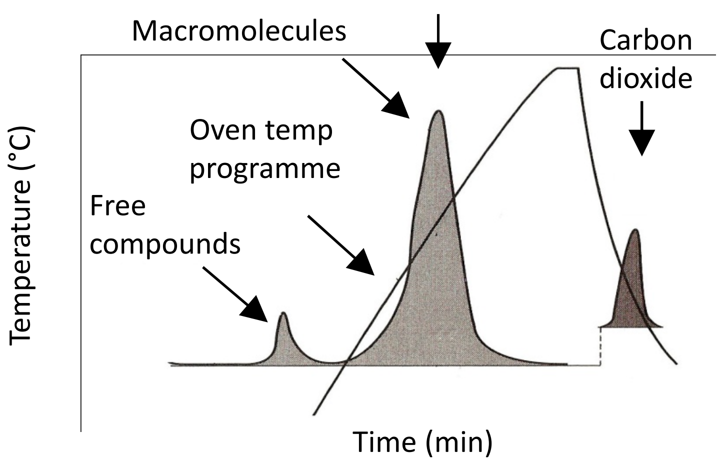
E.g. Total organic carbon



3) Speciation of the carbon

What types of carbon are present?

E.g. RockEval



Increasing resolution

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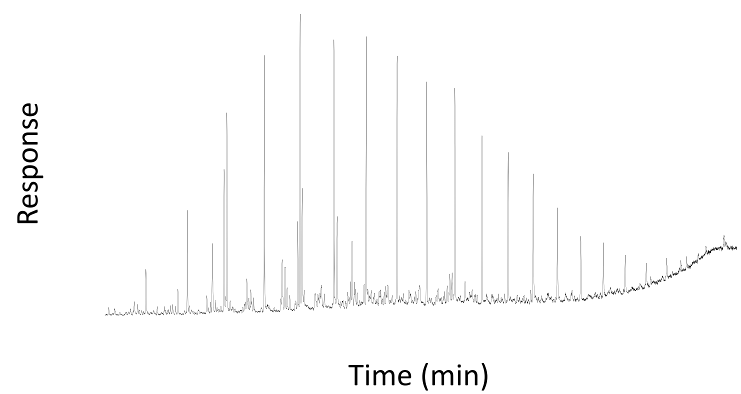
4) Molecules

What molecular fossils are present?



- **Estimated mass needed 1000 mg.**

7c. Sedimentary Rock Component Analysis

Sands and sandstones studied increasingly on "grain by grain" basis to evaluate provenance and sedimentary processes

Single Detrital K-Feldspars
Geochemistry
$^{40/39}$Ar ages
Pb isotope signature
K-feldspars rare on Mars but plagioclase common

Single Detrital Amphiboles & Micas
Geochemistry
$^{40/39}$Ar ages
Nd or Pb isotope signature

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Single Detrital Zircons
Trace elements
O-isotopes
U/Pb ages
Hf-isotope signature
Few zircons on Mars but phosphates common

Lithic Grains (Rock Fragments)
Petrography *Mineral chemistry*
Bulk chemistry *Trace elements*
$^{40/39}$Ar ages *Radiogenic isotope signatures*
mg-sized samples sufficient to carry out most isotope analyses – single grains for very coarse sand; small populations for finer sand

- **Estimated mass needed 200 mg.**

7d. Bulk composition, stable isotope analysis

There are several accepted techniques used
for measuring the bulk composition of planetary materials:

- INAA
- XRF
- ICP-MS
- ID-MS

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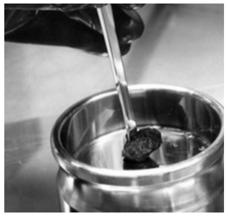
A less widely used approach is modal recombination. This involves point counting for determining the mineralogical mode of the sample plus electron- or ion-microprobe analyses of constituent minerals. This approach does not give high fidelity results due to the following:

- Thin section studied may not be representative of the whole
- Cannot accurately account for elemental zoning within minerals
- Fine-grained basalts have many minerals too small to be analyzed
- Accurate modes are difficult to obtain

- **Estimated mass needed: 500 mg.**

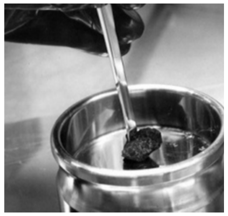
Rock Sample sizing:
How much sample is required?



DRAFT FINDING #20. The optimal mass/sample for rock samples is 15-16 g. The needs for sedimentary and igneous rocks are slightly different.

DRAFT FINDING #21. There would be significant scientific consequences to returning a sample that is significantly undersized (e.g. 40-50% of its planned size). An important science priority is to be able to recognize such cases early enough on Mars that faulty sample collection attempts could be rejected, and the samples reacquired.

Investigation Pathway: Regolith Samples



Sample as received

Bulk Observations

- Stratigraphy?

Hand Pick

Small rocks

- Relatively large rocks/grains assigned a number and become their own sample
- Samples submitted to small sample analysis.
- Specifically seek exotic lithologies.

Subsample Analysis

- Multiple subsample splits prepared for lab analysis:
  - Physical properties
  - Chemistry
  - Mineralogy
  - Age
  - Stable isotopes
  - Spectroscopy
  - Biology
  - Human safety

Acknowledgment: Mike Hecht and granular materials focus group.

Regolith Sample—Sizing

- Approach
  - Bottom up assessment (itemized measurements)
  - Allow for independent verification (2x or 3x)
  - Retain a pristine fraction (40%-67%)
  - *No* allowance for re-use, which would reduce volume
- Context
  - **Desire 3-4 samples for geology, 2 for everything else**
  - Desire fraction of medium-coarse sand for single-grain analysis
  - Independent top down estimate ranged from 1.6 cm^3 (grains only) to 14.3 cm^3 (plus bulk organic and isotope chemistry)
  - Substantially smaller samples (>10 mg) would still be useful. For example, Phobos-Grunt plans to return 200 mg.

DRAFT FINDING #22: A relatively full program of scientific analysis can be done on a regolith sample of about 6 cc. Less complete, but valuable, science could be done on samples smaller than this, but it is not recommended that samples smaller than 1 cc be returned.

Acknowledgment: Mike Hecht and granular materials focus group.

7e. Gas Inclusions in Minerals

Objective:

Igneous rocks

Assess magmatic volatile content and outgassing efficiency by analyzing CO_2 and noble gases (e.g. important are the radiogenic isotopes ^{40}Ar, ^{129}Xe, He)

- **Volcanic outgassing**
- **Evolution of atmosphere**

Ref.		Investigation/Topic
1		**Preliminary Examination before opening**
2		**Peliminary Examination after opening**
	b	Non-destructive science involving whole cores
		INITIAL SUBDIVISION OF SAMPLES
3	**a**	Extant life detection
	b	Biohazard assessment
4		**Pristine storage for future researchers**
		ALLOCATIONS OF SUBSAMPLES TO PIs
5		**Microanalysis of polished surfaces**
6		**Microanalysis of small subsamples (<10 mg)**
7		**Bulk Analyses (typically >100 mg)**
	a	Geochronology
	b	Organic geochemistry
	c	Quantitative sedimentology
	d	Bulk composition, stable isotope analysis
	e	Fluid inclusion, gas extraction

Analysis ➔ *noble gases* :

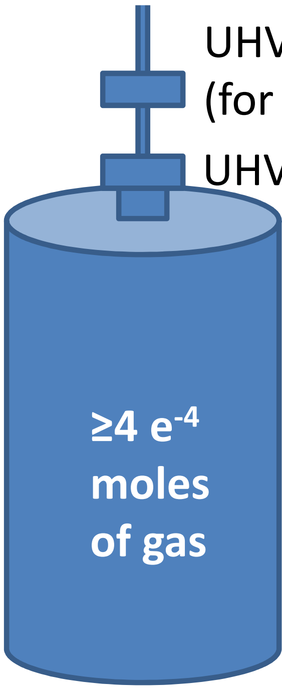
- Extraction from bulk sample (or mineral separate) by crushing and heating
- Required sample mass (based on a Martian meteorite analysis[1,2]) **at least 100 mg / analysis**

Analysis ➔ *major fluid phases (e.g. CO_2, H_2O)*

Single fluid inclusions: in thick sections (fluid composition), elemental and isotopic composition by beam (SIMS) and laser techniques (LA-ICPMS, Raman)

- **Estimated mass needed 100 mg.**

Investigation Pathway—Gas Sample(s)



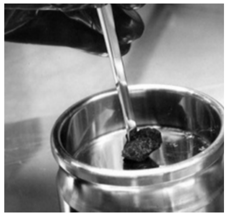
UHV = ultra high vacuum seal

To be performed at sample receiving facility

- Using a UHV vacuum line (noble gas laboratory) , pressure gauge, and constant T
- Check airtightness (terrestrial atmosphere) of valve 2 ➔ noble gas concentration in volume between valve 1 and 2
- Separation of 50% of the gas for future analyses, storage in 2x UHV-sealed container (separation by pressure)
- Same procedure for separation into aliquot gas samples (also in containers that are 2x UHV sealed)
- **20x pressurized** gas sample ➔ sufficient for **9 aliquots** analysed for noble gases at required uncertainties
- ➔ result in **triple analysis by 3 different investigators**

NOTE: a double valve would be scientifically valuable (better sealing) AND to be able to assess the quality of the sample at the time it is received. Having two valves would also simplify the later sample handling.

Gas Sample—Sizing



On Mars surface:

Atmospheric pressure at 0 km	**700 Pa**
Mean temperature	**223 K**
Sample volume	**0.00005 m3**
Compression factor	**20**
Returned Gas amount:	4E-04 mol = **2E+20 atoms**

Resulting amounts per aliqout

4E-04 mole / 2 (storage) / 9 (aliquots) :

^{4}He	1.5E-11 mole
^{20}Ne	4.8E-11 mole
^{36}Ar	1.1E-10 mole
^{84}Kr	1.4E-12 mole
^{132}Xe	1.2E-13 mole
N_2	5.7E-9 mole

[1] Best sensitivties ETH Zurich noble gas lab

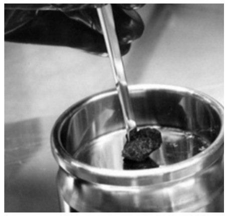
	(count/s)/ccSTP	
He	7.10E+14	Tom laser, 40eV
Ne	3.12E+15	Tom laser, 40eV
Ar	5.03E+14	Alb, laser
Kr	1.59E+15	Alb, laser, 100eV
Xe	2.04E+15	Alb, laser, 100eV

[2] CRPG CNRS Nancy, France, B. Marty

UPDATE TO TABLE 1 OF ND-SAG (2008)

DRAFT FINDING #20. Gas sample quantity recommended is equivalent to 50 cm³ at a pressure 20x Mars ambient.

The Importance of Replicate Analyses



3

SCIENCE FLOOR

2

1

NUMBER OF INDEPENDENT DETERMINATIONS

A central principle in science is that results need to be reproducible. This is especially true for extraordinary discoveries. This can only be assessed through multiple determinations, which gives quantified information on accuracy and precision.

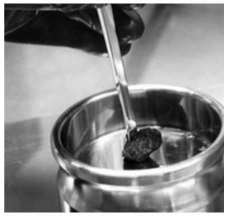
DRAFT FINDING #18. The samples should be sized so that all high-priority scientific measurements could be done in triplicate, in different laboratories, under the leadership of different principal investigators, and if possible using different methods.

What makes measurements independent?

- Different investigators (REQUIRED)
- Different laboratories (REQUIRED)
- Different analytic method (DESIRED, but only if appropriate)

Pre-decisional: for discussion purposes only

Conclusion

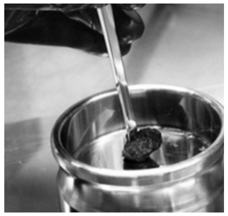


SEDIMENTARY		IGNEOUS			
Mass (g)		**Mass (g)**		**Goal**	**Technical notes**
total	meas.	total	meas.		
Phase I Initial Examination					
0.00		0.00		Get enough info. to make decisions about what to do with sample. How heterogeneous? How to sub-divide? Large scale mineralogy and surface	Preliminary examination using stand-off instruments only; non-destructive
0.00		0.00			Preliminary examination using stand-off instruments only; minimally destructive
Phase II Planetary Protection					
1.50		1.50		Assess life and biohazard	
Phase III. Research					
1.85		1.21		Microanalysis of polished surfaces	Inorganic chemistry, organic chemistry, mineralogy, petrology, isotope geochemistry. Assume a need to prepare 5 thin sections and 1 thick section from each sample.
				Fluid inclusion analysis. Demountable thick sections (100 mm thick)	
0.15	0.05	0.15	0.05	Microanalysis of individual subsamples -- number depends on heterogeneity	Inorganic chemistry, organic chemistry, mineralogy, petrology, isotope geochemistry
3.00	1.00	3.00	1.00	Bulk Analyses	Soluble & insoluble organic analysis
		2.25	0.75		Internal isochron geochronology, multiple isotopic systems.
1.50	0.50	1.50	0.50		Bulk composition; stable isotope geochemistry
0.30	0.10	0.30	0.10		Gas extraction by crushing and heating to get major fluid phases (CO_2, H_2O, perhaps some noble gases)
0.60	0.20			Clastic sediment component analysis	number of grains analyzed (≥100) and number of distinct components (e.g., lithic, phosphate, plagioclase grains). Individual lithic grains of ≥1 mg required for analysis
1.00		1.00		Follow-up for unexpected results	
Phase IV. Sample Mass held for Future Researchers					
6.00		6.00		Future research	Pristine storage for future researchers
15.9		16.9		Subtotal	
5%		5%		*Factor for sample re-use and future improvements in efficiency*	Current figure is a conservative guess. Needs detailed study by a future science planning team
15.1		**16.1**		**Total sample mass**	

Transition to Scott

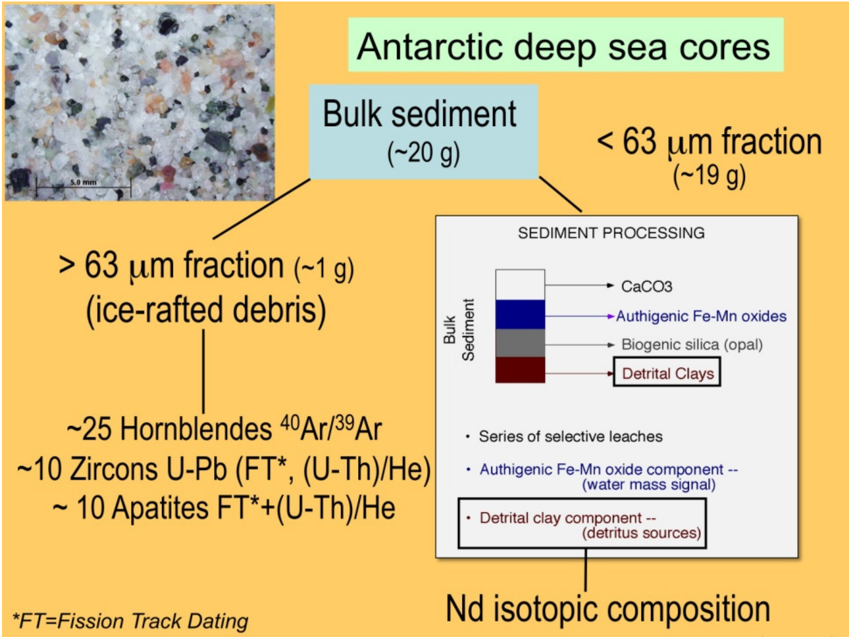
BACKUP

Sedimentary Rock Analysis
An Example from Antarctica



Mapping Subglacial Antarctica with Ice-Rafted Sediment

- *Sands (>65 µm) in deep-sea cores represent ice-rafted debris; most is quartz (not analyzed)*
- *Significant numbers of single grains of accessory phases (hornblende, zircon, apatite) are present*
- *These are dated individually by multiple techniques*
- *Trace ice berg migration; identify subglacial terrains*
- *Fine-grained sediment treated separately to isolate detrital fraction and this is analyzed separately*

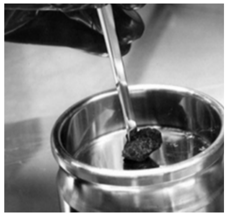


courtesy S. Hemming & E. Pierce (LDEO)

Some Lessons for Sizing Mars Samples

- *Martian sandstones do not contain quartz; likely composed of volcanic rock fragments, mafic minerals (e.g., olivine, pyroxene, plagioclase) and accessory phases*
- *Such grains analyzed individually for mineralogy, chemistry and possibly $^{40/39}Ar$ dating; depending on size and composition other isotopes measured on ≥1 mg single grains or small populations*
- *200 mg samples should provide sufficient material to extract equivalent of ≥100 medium-coarse sand sized grains, allowing for cements and fines, giving robust statistics*
- *Accessory minerals will differ (e.g., oxides, phosphates) but amount/composition cannot be determined ahead of time – such grains would be analyzed on an "as found" basis*

7c. Sedimentary Rock Analysis
Chemical Sediments & Fluid Evolution



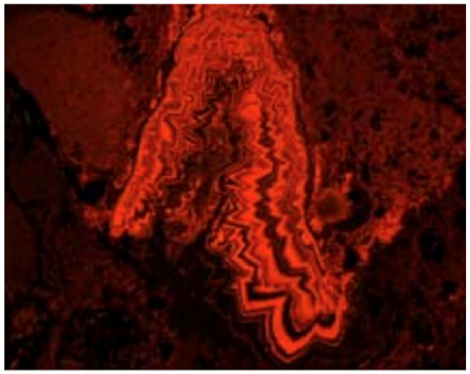
Modern studies of chemical sediment and chemical constituents (e.g., carbonate, sulfate) require increasingly higher spatial resolution

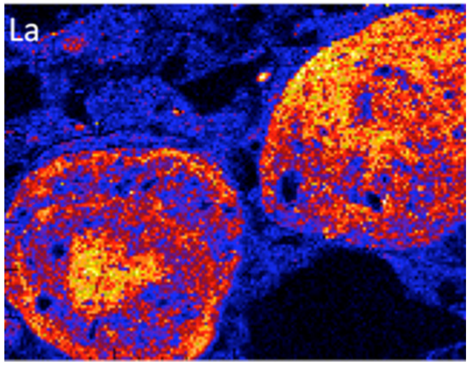
Tracing Fluid Compostions

- *Precipitated minerals (e.g., sulfates, carbonates, halides) reflect fluid chemistry*
- *Temporal evolution of fluid chemistry reflected in mineral zonation*
- *Higher resolution sampling permits greater time resolution*
- *Trace elements, stable isotopes, radiogenic isotopes all reflect fluid compositions*

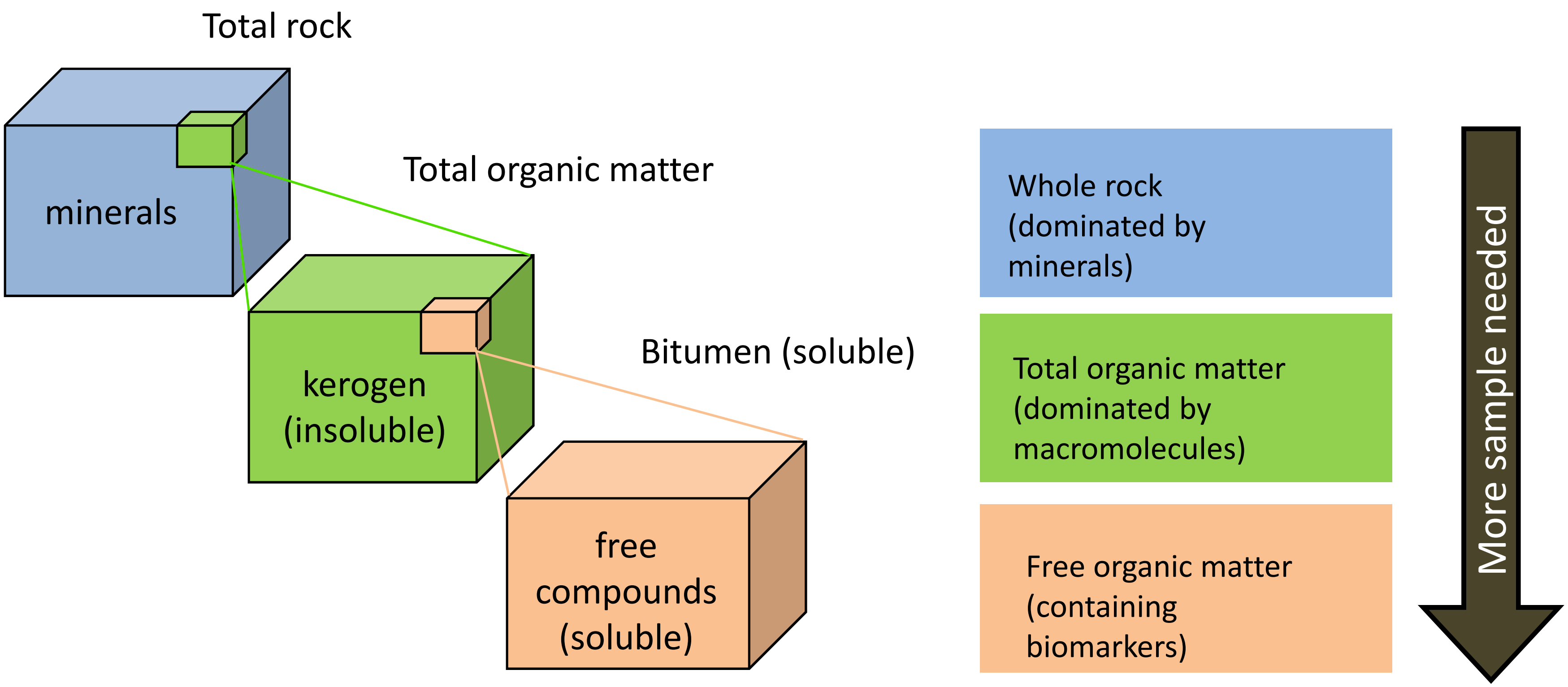
Microsampling

- *To achieve higher spatial resolution, move to minimally destructive laser/beam methods (e.g., LA-ICP-MS; nano-SIMS; synchrotron micro-XRF)*
- *Microsampling techniques still in common use for isotopes – typically ~1 mg samples drilled from fresh surfaces*
- *Number of microsampled aliquots depend on number of distinctive constituents and geometry*





7b. Organic Geochemistry
Accessing organic fractions



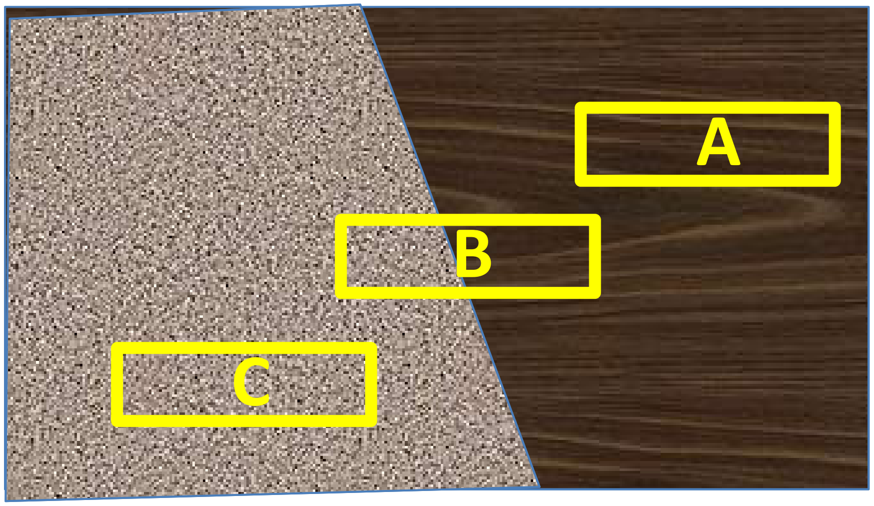
- Rocks are dominated by minerals so their analysis requires relatively small samples
- Organic matter present in smaller (few %) amounts, so would require relatively larger samples
- Free organic matter is trace component so would require relatively large samples

Strategies to Deal with Rock Heterogeneity

The calculation of mass required per sample assumes the sample is homogeneous…. But all samples would be heterogeneous at some scale.

Heterogeneous samples are often scientifically valuable and even if there is macroscopic heterogeneity evident at the time of sample collection (as shown below) these samples should not necessarily be 'avoided'. Rather, **we need to consider the investigations likely to be carried out and the resulting mass requirements**.

EXAMPLE:
How should this rock be sampled?



…Depends on the question!

- For some hypotheses, there is important information in the contact: Sample B.
- For other studies, maximizing mass for petrology/geochem is crucial: Samples A and C.
- One lithology may be more important: Sample A or C.
- ***Decision needs to be made by the future science ops team.***